Naval Research Laboratory

Washington, DC 20375-5000

NRL Report 9279

Considerations in the Design and Development of a Human Computer Interaction Laboratory

LISA B. ACHILLE

Human Computer Interaction Laboratory
Information Technology Division

September 20, 1990

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 20, 1990

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
Considerations in the Design and Development of a Human Computer Interaction Laboratory

5. FUNDING NUMBERS
TA RR015-09-41

6. AUTHOR(S)
Lisa B. Achille

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Research Laboratory
Washington, DC 20375-5000

8. PERFORMING ORGANIZATION REPORT NUMBER
NRL Report 9279

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
Arlington, VA 22217

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The author outlines the design and development of a Human Computer Interaction Laboratory; discusses preparatory system design stages; defines operational requirements; identifies laboratory functions; addresses architectural and environmental features (such as lighting, soundproofing, and electrical service) as they relate to the special needs of a research facility; evaluates equipment subsystems (particularly audiovisual recording systems), and presents equipment lists and a design considerations checklist.

14. SUBJECT TERMS
Functional area design
Architectural design features
Audiovisual equipment subsystems

15. NUMBER OF PAGES
24

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

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FOREWORD

This report is a guide for defining and developing a behavioral research laboratory. The author assumes that experimenters will observe experiments in progress both directly and electronically and will record the proceedings. Although the report is geared toward behavioral scientists in human computer interaction (HCI) research, the ideas and plans can be used by scientists involved in other classes of research.

Design considerations for the development cycle are included, but the guidelines are also intended as a reference if only portions of the information are needed. The Contents can also be used as an annotated checklist by the design coordinator responsible for the development process. In our context, the position of coordinator or laboratory design coordinator could be a researcher, an administrator, or a member of some other professional group. The guidelines are general because of the wide variability in laboratory missions. The recommendations are not exhaustive, and the coordinator will frequently be referred to design or equipment professionals for expert information.

CONSIDERATIONS IN THE DESIGN AND DEVELOPMENT OF A HUMAN COMPUTER INTERACTION LABORATORY

1.0 INTRODUCTION

The design and development of an experimental facility is a complex process that shares characteristics with the production of any multifaceted system. Many factors must be considered and tradeoffs must be made because of the interplay between the physical environment of the facility itself, the research goals of the organization, and the implementation of the facility [1]. Woodson's steps for system development simplify and organize the process [2]. Successful system development begins with an analysis process that defines an operational concept to direct the progress of the project and provide a framework for design tradeoffs and decisions. The operational concept encompasses organizational mission, functional identification, and operational requirements. Concept formation is followed by preliminary design and evaluation, more detailed design, and prototype development and testing. When necessary, design modifications are made to correct problems identified in system tests [2]. This report is limited to the laboratory design in the prototype design stage.

1.1 System Development

1.1.1 Performing an Analysis

Standard human engineering analysis practices are applied to the task of concept formation. Although we assume that an organization that has identified a need for an experimental facility knows what it hopes to accomplish through the acquisition of a laboratory, organizational goals still need to be formalized. The mission and subgoals of the organization must be defined. This information will help to focus coordinators and designers when making design decisions or tradeoffs.

When mission goals are determined, next identify the groups and individuals that will use the facility. Most laboratories provide for researchers, technicians, experimental subjects, visitors, observers, and visiting VIPs. Depending on particular laboratory applications, some jobs might also include training specialists, management, or administrators. A very large and comprehensive laboratory might require engineers, mathematicians, statisticians, sociologists, physiologists, operations research specialists (simulation), and interns or junior and visiting scientists [3].

When the user groups are identified, the user characteristics that will influence laboratory design can be specified. Usergroup characteristics vary by facility, mission, and group composition. For example, unless the user group is heavily populated by technicians or other practitioners, the coordinator can assume that the users know little about the specifics of operating the equipment comprising the audiovisual (A/O) system, even though they are knowledgeable in their own areas of expertise. In this case, the coordinator can assume the need for extensive user training for complex systems. Alternatively, the coordinator can direct the equipment contractor to make system operation transparent to the user by way of a clever design or by using built-in functions.

Manuscript approved April 13, 1990.

1.1.2 Identifying Functions

The coordinator now decides the functions (by areas) that the laboratory performs to accomplish mission goals. From this, we determine the functional areas and the space requirements. (The equipment needs will be discussed later.)

1.1.3. Defining Operational Requirements

Operational requirements and constraints are defined to identify the demands that will be made on the laboratory system. Outline an operational concept to further describe how the laboratory will be used. Analyze the kinds of research and the types of experiments to be conducted for operational requirements. For instance, a group planning to conduct protocol analyses and group interaction studies might have different requirements than a group of researchers planning to conduct high-fidelity simulations, system degradations, or performance studies. Although the kinds of planned studies vary from group to group, once research direction decisions are made, the analysis process for determining operational requirements is nearly the same. Next, the coordinator should talk to all prospective researchers who will use the facility to get their ideas about the experiments they hope to do and what their needs are for space, equipment, subject observation, and computer support. The coordinator should address special needs or requirements associated with a particular group.

When participating researchers have been polled, their needs and operational constraints can be analyzed and itemized. When all user information is received, it is necessary to determine capacity requirements, such as whether there is a need to conduct one or more experiments simultaneously or to assess whether careful planning and coordination would reduce operational requirements. In general, the coordinator uses the information gathered from the potential users to decide what roles humans are to be assigned; and when, where, and how humans will interact with subsystems and components—whether indirectly or directly. Valuable information can be obtained by visiting other labs in government and industry and by talking to their staff about the development process of designing their own laboratories, equipment needs, capabilities, lessons learned, and tradeoffs.

In addition to requirements that are directly associated with experimentation, coordinators must determine the available space and its layout. Then the adequacy of the room configuration is assessed.

Next, an inventory of available equipment is taken to identify the equipment available for communal use and the equipment that needs to be upgraded to meet expanded use criteria. Some of the equipment needed for the new laboratory is probably already available within the organization.

When present operational requirements are outlined, the coordinator considers future needs and whether or not the design will meet them. In some cases, future needs can be addressed by incorporating flexibility and portability of equipment into the preliminary system design. (See Sec. 4.5). In some cases, the range of experiments will vary over time, and these facilities will need to be more flexible. For some applications, it may be more cost effective to buy a larger scale equipment system than is initially necessary because it would be more costly to retrofit or augment the original system later. Consider phased development to incorporate planned growth or to accommodate budgetary constraints.

Lastly, the coordinator considers the work environment, such as heating and air conditioning, lighting, and noise control. We later discuss special environmental or architectural requirements required by the extensive use of equipment common to behavioral laboratory facilities.

2.0 GENERAL DESIGN

Once requirements are identified, the design process begins. Laboratory spaces are divided by the determined functional areas. Wall and floor space must be considered as well as furniture, storage, work areas, meeting areas with information display capability, and an attractive reception area for guests and official visitors. Plans for future expansion are included at this stage.

The layout plans or designs needed by group members is documented. This allows group review and provides information for potential contractors, architects, professional designers, and planners. Several commercial software products are available that can be used for architectural drawings. Using a software-based product will facilitate modifications to the evolving design during the inevitable iterations and allow designers to try various configurations. If a design consensus is required, such a drawing package will facilitates these changes. Also design decisions that do not relate to layout planning must be documented.

2.1 Functional Areas

Candidate primary functional areas might include, as a minimum, experimental space, work areas for set up or equipment control, storage areas, and office space for laboratory personnel. (The design and allocation of office space is not discussed in this report.)

In addition to the basics, secondary functional areas, such as meeting rooms, interview and debriefing areas, demonstration areas, and editing spaces might be included. If an audio and/or visual recording system is planned, a separate control area may also be necessary.

Coordinators should consider using a space for more than one function (for example, debriefing, meeting, working, and editing). Functional areas can be combined (such as working, editing, and storage) as long as sound insulation is adequate. With proper scheduling, meetings, debriefings, demonstrations, and experiments can all be done in the same space. The use of soundproofing maximizes flexibility and multiple functionality, especially if auditory experiments are to be run. There is an obvious trade-off between the additional cost of using sound-isolating building materials and the cost of constructing additional work space dedicated to a single function. (See Sec. 3.2).

Most laboratories average a scheduled occupancy rate of 50% or less. The extent to which functions should be combined within a given space should be made based on several considerations. These include

- the kinds of equipment being used,
- the number of people working at a particular function,
- the diversity of their tasks,
- the types of studies being conducted
- the number of test participants that are planned,
- the number of observers that will be present, and
- the mission and general requirements of the facility.

If simultaneous experiments need to be run continuously, it is difficult to combine experimental space with demonstration or meeting areas. For instance, for laboratory applications where little recording is done the experimental space could occupy a small portion of the total area. The control panel could be placed in a general work area. In many facilities, the control panel console is housed in its own room or booth to allow experimenters to communicate and to adjust equipment without disrupting the recording proceedings. (See Sec. 4.2.) Other usage considerations can determine design characteristics of secondary functional areas as well as a scheme for combining primary functional areas.

The layout and design of the secondary areas varies depending on the size and mission of the particular laboratory. In most cases, variations or weaknesses in the design of the secondary functional areas has little or no impact on the overall success of the laboratory because they are generally less crucial to the research mission. The most beneficial guidelines relating to the secondary functions concern the equipment used to perform them. More information on equipment characteristics is given in Sec. 4.0.

2.1.1 Experimental Spaces and Work Areas

With the information about operational requirements determined, coordinators can decide how many experiments they will wish to conduct simultaneously and delineate the scope of the overall operation. If there are plans to conduct more than one experiment at a time, more than one test cell will be needed. Alternatively, one large test cell that could be subdivided to permit equipment set up while experiments are in progress would serve the same purpose while providing additional flexibility. Provisions to control noise may be necessary when multiple activities are planned in a subdivided space.

Factors other than the frequency of experiments can influence space requirements. If only the efficiency of scheduling and space allocation are considered, there could be problems for experiments that require equipment to remain set up and in place between experimental sessions. Flexibility and cost effectiveness are enhanced when laboratory areas can serve double duty as experimental space and setup or work space. In most cases, physical resource trade–offs will be driven by budget considerations rather than strictly by needs. To conserve resources, incorporate as much flexibility and multiple functionality of work space as possible.

2.1.2 Storage Areas

Storage needs vary with the type of operations. If the operational concept includes extensive videotaping, there may be a nned for a large storage area for recorded video tapes. The organization must decide how to store the videotapes of the completed tests. The expected frequency of tape review should determine the accessibility of planned storage.

It may be desirable to provide library space if a collection of journals or operator or maintenance manuals is planned for the group. There should also be space to store extra, unused, or intermittently used equipment (such as extra chairs), which are used only for occasional demonstrations.

Storage needs are not limited to intermittently used items. Specialized storage equipment (e.g., cabinets) may be needed to protect equipment in constant use, such as computer processing units. (See also Secs. 3.2. and 3.3.)

2.1.3 Furniture Placement and Traffic Patterns

All work space and experimental areas should be sized by determining the maximum number of people that will use the space and by the amount and size of the equipment and furniture that they will need. Preplanning equipment and furniture placement is important because this often impacts the final size of the facility. For example, if ceiling–mounted lighting and/or camera equipment are desired, a nonstandard ceiling height may be necessary.

When designing and arranging furniture thought must be given to furniture and door placement, traffic patterns, and the interchange between functional areas. For example, although only limited access may be required between projection areas and demonstration areas during actual demonstrations (particularly when remote control devices are used), physical access between these two areas may be necessary when preparing for an event. Adequate clearance must be left between stationary objects to allow easy movement of people and portable equipment. Door openings must be placed and sized to allow adequate passage for people and equipment. Furniture must be designed and placed to facilitate cleaning and possible future rearrangement.

Since work space and furniture needs will vary widely between laboratory operations, a good handbook is recommended (such as Woodson [2] or McCormick and Sanders [4]), which includes guidelines for interior space design, the ergonomic design of office chairs and other furniture, and the recommended space per person, for desks, and for chairs. The Woodson reference also contains information about furniture selection and use as listed below.

- User efficiency: The users' tasks must be considered, and the furniture should be arranged accordingly, taking into account operation of special controls, accessibility within components, and visual impact of finishes. (See Sec. 3.6.)
- Interactive characteristics: How one piece of furniture interacts with another positionally must be considered, also, in terms of orientation and interference.
- Safety: Potential safety hazards including must be considered sharp contact points, fragility of the structure, balance and stability, and flammability. (See Sec. 3.8.4) [2].

3.0 ARCHITECTURAL DESIGN FEATURES AND CONSTRUCTION CONSIDERATIONS

Planning needs will vary depending on whether new construction or renovation are planned. Determining existing construction methods and the location of load-bearing walls are best left to professional architects or building contractors. As always, budget will also be a major concern. Regardless of whether the facility is being renovated or is of new construction, several architectural features relating to laboratory facility design must be considered.

3.1 Surfaces

Floors should be carpeted to reduce noise from intralaboratory traffic. Carpeting should be of a medium tone in color. If the laboratory space is to be used for videotaping, orange, green, and red tones should be avoided because they are not conducive to high-quality video production. Blue and beige tones are best for this purpose. The darkest tones should be avoided because they absorb light, thus reducing the light intensity required for quality video production. (See Sec. 3.4.) Low-piled carpeting facilitates cleaning and equipment relocation, while densely woven industrial grades are the most durable.

If budget restrictions allow and ceiling height permits, raised flooring with carpeted panels should be considered. Most types of raised flooring are of modular construction to allow removal of individual panels to facilitate the maintenance or modification of computer cable and other wires stored underneath the floor. Carpeted raised flooring panels are beneficial if noise is a concern. The expense of raised flooring is sometimes justified if access to cabling and wiring is needed to provide flexible equipment use and interchange.

Dropped ceilings are generally advantageous. The inexpensive panels are accessible and provide some sound absorption. (See Sec. 3.2). Since dropped ceiling panels are easy to remove, they can sometimes serve as an inexpensive substitute for raised flooring if proper conduit is used to carry computer cable or power lines. The architect or electrical system designer can offer guidance.

Carpeting can be used as an inexpensive and potentially attractive covering for walls of concrete, cinder block, or other undesirable material. Fire code regulations for the area must be checked along with the intended use of the space. Carpeting can also double as an oversized bulletin board for laying out plans, proposals, or other space-consuming papers.

3.2 Soundproofing

The importance of soundproofing is not limited to laboratory applications that include speech and auditory research. When efforts have been made to pack maximum functionality in a minimal, cost-effective space, sound insulation of separate functional areas is critical. Several steps can be taken toward that goal.

Walls in all new construction should be insulated with fiberglass or constructed with soundproofing covering. Carpeting can be used on the wall as well as floor surfaces to absorb excess noise and insulate adjoining nonlaboratory spaces. Sound absorbing panels or acoustical tile can be used for dropped ceilings or to resurface existing ceilings. When large, high-ceilinged spaces are partitioned and finished with dropped ceilings, careful attention must be paid to insulating the ceiling spaces near the room dividers. Often in new construction, room dividers do not extend past the new finished ceiling height, and this allows sound to be transmitted in the spaces above the dropped ceiling.

Sound insulation in and around rear projection rooms is particularly important because many projection display screens transmit stray noise. Projection screens made of fabric or other flexible material and mounted directly into the wall structure are especially susceptible to this problem.

New doors should be of solid-core construction or be sound insulated. Where noise is a serious problem, rubber gasket seals can be used around door openings to reduce sound transmission. Sound or noise control can also be effected by using carpeting.

Coordinators should consider constructing separate rooms or sound-insulated areas for noisy pieces of equipment. Adequate ventilation and cooling capacity must be provided for those areas.

3.3 Temperature Control

Air-conditioning systems should run quietly to reduce the potential for interference with recording equipment and operations. If laboratory spaces are designed to allow for the subdivision of large spaces into smaller units, room air-conditioning vents must be carefully located to provide adequate cooling capacity for all spaces. Placing vents directly over work areas must be avoided. Where the designer houses the computer or other noisy equipment in a separate enclosure, special air conditioning may be required for that enclosure.

In most cases, the designer of a cooling system will provide more capacity than is necessary to ensure adequate cooling under extraordinary circumstances. If extensive use of computer or other heat-generating equipment is planned, the design engineer should be apprised of the kind, quantity, and heat production of planned equipment. The air-conditioning design engineer will need to know how many people will be using the various rooms in the facility. This information must be provided in British Thermal Units (BTUs) per hour. For example, the average person gives off about 500 BTU/h, the average personal computer produces 1000 BTU/h, and a standard four-tube fluorescent lighting fixture will give off nearly 700 BTU/h.

If heat production in BTU/h is not available from equipment manufacturers, it can still be estimated if the amperage requirements for the equipment are available. Watts of power is computed with watts = amperage times voltage, or $P = I \times E$. The required voltage is either 110 or 220 V for most kinds of equipment. BTU production is then estimated by multiplying watts by 3.41. The engineer will then design the system to provide a ton of cooling capacity for each 12,000 BTU of heat production [5].

There are no additional special considerations for selecting a heating system for a behavioral research facility. If a new heating system is planned or changes are made to an existing system, standard concerns (noise, efficiency, flexibility, and ease of use, adjustment, and control of any new heating system) should be explored.

3.4 Lighting

General and supplemental illumination must be considered. Supplemental illumination or task lighting can be used either when general lighting is unnecessary or in addition to general lighting. The need for this kind of lighting depends on the type of tasks and functions that are determined during the system-development phase. Woodson [2] and McCormick and Sanders [4] provide tables of general illumination guidelines that list task requirements against light level in foot-candles (fc) and by type of illumination.

High light levels (150 fc) are desirable for producing quality video recordings. This level is generally too bright to simulate normal working environments and can cause significant glare problems for test participants and observers. A compromise level of 100 fc is adequate for video recording. It would be perceived as being brighter than the normal office-space illumination (30 to 40 fc). Fluorescent lighting is adequate for most applications. To simulate special environments, such as military lighting, it may be advisable to offer a combination of lighting types—for instance, both fluorescent and incandescent.

In special cases and with certain types of display or recording equipment, the amount of flicker from fluorescent lights is unacceptable. High-frequency fluorescent lamps that are expected to help with the traditional flicker problems have recently become available. Incandescent lighting will also help with flicker problems, but to a lesser degree. If the amount of flicker from AC incandescent lighting is unacceptable for special applications, wiring should be installed to permit use of direct current for flicker-free lighting. (See Sec. 3.7.)

The naturalness of the color spectrum (compared with sunlight) of various types of lighting varies. Incandescent lamps are stronger in the red and yellow regions of the spectrum whereas fluorescent lamps provide a higher proportion of light in the blue range. These factors are to be considered when choosing lighting. In some cases, the lower cost of fluorescent lighting overrides the spectrum considerations.

Monochromatic (single hue) lighting should be avoided because of its potential for distorting general color perception. When certain military or other special environments are to be simulated in an experimental setting, monochromatic lighting may be desirable.

Track lighting, rather than fixed spot lighting, should be used to provide versatility.

3.5 Lighting Control

Good lighting control optimizes seeing conditions by enabling adequate light level adjustment and independent light source control. Installation of a central lighting control panel promotes efficiency and energy savings. Independent "local" lighting control is also desirable to allow lighting adjustments without having to interrupt ongoing laboratory activities to reach a central lighting control panel that may be in a separate area.

Installing dimmers on all lights facilitates lighting control for use with one-way mirrors. One-way mirrors rely on a light intensity differential between the areas they divide to allow selective viewing. Dimming is especially important when CRT-type displays are anticipated. Lowered light levels improve the visibility of computer screens and other projected images such as slides, viewgraphs, and movie or rear projection screens. Independent and dimmable controls promote energy savings by allowing light to be provided only where it is needed and in the amount needed. If visual dark adaptation is required, dimmable lights capable of ranges between 0.01 and 2.0 fc should be provided [2].

3.6 Glare and Shadow Control

To control glare and its accompanying fatigue, light sources should not be directly visible to the observer [6]. Deep-cell fluorescent fixtures are a good example of shielded light sources. Otherwise, baffles, screens, or shades—especially on windows—can be used. Where possible, low-gloss surface material should be used on work surfaces, particularly in front of the observer. Fluorescent light sources are most desirable in glare and shadow prevention because of their diffusing nature [2].

When rear projection screens (either wall-mounted or free-standing models) are used, stray light and glare control is especially important because many such screens will transmit light easily in both directions. When stray (nonprojected) light contacts a rear-projection screen, display brightness and clarity are diminished. Where practical for wall-mounted rear projection screens, a matte black paint finish should be applied to the walls and ceiling of the projection room to absorb nonprojected light that might otherwise be visible from the viewing side of the screen. Dimmers should be provided to control light levels in the room from which the display will be viewed.

Room-darkening shades should be provided for blocking light or view for all exterior windows and one-way mirrors. If extensive light control is required (e.g., when rear projection screens are used), shades fitted with tracks that enclose the sides of the blinds further reduce the amount of light infiltration around window edges.

Shadows are caused by an improper placement relationship between light source and observer. If the location of the observer is fixed, the light source should be placed to the left-hand side of the observer to cast light over the left shoulder [2]. Alternatively, workstations or movable light sources (such as track lighting) are judiciously placed to prevent shadow problems.

3.7 Electrical Service and Cabling

Although power-demand analyses and electrical-service designs are usually handled by an engineer, the coordinator provides sufficient information to ensure the proper sizing and functionality of the new electrical system. The power requirements of all planned equipment should be given to the electrical engineer so that the engineer can determine the total amperage of the service. Some equipment manufacturers recommend that their products be operated on a dedicated electrical line of certain amperage. If direct current electrical service is required, all wires should emanate from a central point where they can attach to a transformer for efficient conversion from the standard supply. Even with careful planning, it is considered prudent to provide for future expansion in the circuit-breaker panel.

The coordinator may also specify electrical receptacle numbers, locations, and types, particularly if there are special needs. Under normal conditions, grounded receptacles should be closely spaced and placed approximately 3 ft above the floor to be accessible when furniture and equipment are in place.

The cost and benefits of power-surge protection devices should be weighted, although many manufacturers are incorporating surge-protection devices into their products. The reliability of the local power source and the likelihood of lightning strikes should be considered. Some kinds of equipment (and experiments) require an uninterruptable power source (UPS), which consists of a set of batteries that store power when there is a break in electrical service. The installation of a UPS must be discussed with an electrical system designer.

For laboratories where flexibility is necessary or accessibility is required, the addition of new wire or cabling should be provided when new equipment or new configurations of old equipment are needed. Either dropped ceilings or traditional raised floors will provide this access. If neither of these options is available, commercially available cable conduits or channeling should be considered. When exposed wires or cables are necessary, use hooks and wire supports mounted along the wall to keep cabling off the floor to prevent damage and accidents. If cabling is not concealed below the floor or above the ceiling, a method of passage between adjoining spaces should be considered. If wall openings are made to accommodate exposed cabling, expandable apertures that would restrict the passage of light and sound around the cabling may be desirable (see Secs. 3.5 and 3.2).

3.8 Specialty and Miscellaneous Items

3.8.1 One-way Mirrors

If you want direct visual communication between experimental spaces and control or observation areas, provide one-way mirrors for viewing. Glass for one-way mirrors is treated on one side with a special coating that provides reflectivity when there is a light intensity differential between the spaces divided by the glass. A less-expensive and slightly less effective method that uses two sheets of glass is also available. One sheet is mounted at the proper angle to reflect light; when different amounts of light are in the two adjacent rooms the mirror divides. (The proper angle may vary with the characteristics of the glass and the locations of lighting fixtures in the two adjacent rooms.) Sound isolation capabilities of glass and mirrors, which vary by construction method and manufacturer should be investigated. Since one-way mirrors work because of the difference in light level of the rooms they divide, all one-way mirrors should be equipped with drapes to block the light and/or provide visual isolation, when necessary (see Sec. 3.5).

3.8.2 Partitions

Accordion or folding panel walls should be used to divide rooms to enhance flexibility of space usage. Although panel walls generally provide more sound isolation than do draperies, they are not necessarily comparable to fixed construction walls except in the most expensive versions. The sound-insulating rating can be supplied by the manufacturer and should be carefully considered if noise control is a concern. Ceiling-mounted draperies are used to partition areas within laboratory spaces when sound insulation is unimportant. Oddly shaped or curved areas are partitioned by using a custom-formed drapery retaining track.

3.8.3 Projection Systems

Special architectural considerations may be necessary when large projection screens are planned. For example, supplementary framing and support may be needed for rigid, rear-projection screens. For very large screens of rigid construction, consider building access, door size, and corridor sizes before choosing screen size. On occasion, large screens have been lowered by crane through a temporary roof opening, and this is sometimes the most viable alternative. Usually no special architectural treatments are necessary for flexible or stretched screens.

The height of the viewing room is important when planning large screens. For very large displays, a high ceiling is necessary. The bottom of the screen should be mounted no lower than 3 ft off the floor unless only one row of viewers is expected. Otherwise, viewers seated behind the first row would be unable to see the lower portions of the screen. In an amphitheater, mounting height restrictions are somewhat reduced and depend on the steepness and shape of the seating area.

Screen size also partially determines the viewing room depth and width. Depth of the viewing room (from screen location to rear of the room) must allow for adequate distance between the screen and its nearest viewer. As a guideline, screen width determines the minimum viewing distance (from screen to viewer). When possible, a minimum seating distance 1.5 times the screen width is preferable. Screen width also influences the optimum room width. Although distortion effects vary between projection systems, it is advisable to maintain a viewing angle range (from screen outside edge to viewer) of between 60° and 90° [7].

The depth of the projection room becomes important when rear projection on a wall-mounted screen is planned. Adequate throw or projection distance (distance from the projector lens to the screen) must be available to allow the projector to be far enough away from the screen so the projected image size matches the desired screen image size. The throw distance is determined by the width of the projected image times a factor that is generally provided by the projector manufacturer. For example, one installer recommends that the minimum projection room depth be 13′ for a screen 8′ h x 10.5′ w. The estimate must include the added depth of the projector itself (behind the lens). The path of the projected image my be folded by bouncing the projected light off a reflecting surface, but the estimates of lost resolution with this method vary between 2% and 25% for each reflection. Specialized mirrors or mylar covered surfaces are used to construct the reflector. Calibration of the equipment is more difficult when path folding is used.

The mounting technique for forward or rear projectors does not impact room size, but it does influence other architectural considerations. If ceiling-mounted projectors are planned, it may be necessary to supply supplemental ceiling support to accommodate the extra weight. Some projector models require a dedicated electrical supply close to the mounting location (see Sec. 3.7).

3.8.4 Safety and Security

There are no safety or security considerations specific to the design of a behavioral research facility. If power cables are installed under raised floors, a cutoff switch must be located outside the room to remove power in case of fire or other emergency. Because the laboratory may contain expensive equipment, security precautions should be taken. Cypher locks (door knobs fitted with a combination) strike a good balance between accessibility and security. Doors that provide passage between nonexperimental areas (or other areas where light control is unnecessary) should contain windows to prevent accidental collisions. Experimental areas should be equipped with labeled indicator lights or signs to show which rooms are in use. Obstructions (loose cables, furniture, or equipment) in major traffic zones should be avoided. Common sense and general safe practices, such as following manufacturers' recommendations for equipment use must be applied.

4.0 EQUIPMENT SUBSYSTEMS

Designing and selecting equipment systems require considering many factors and thus should not be postponed until facility construction is complete. Architectural and equipment considerations often interact, so early specification of equipment will reduce the number of design changes that might be necessary to the architectural plan. As with many of the architectural design tasks described, the final stages of equipment system selection are best left to the professional designer when more than minimal complexity is expected. A professional systems designer has the advantage of being familiar with all of the various interface requirements and is aware of new developments in equipment technology.

The coordinator, however, must provide the equipment designer with as much information as is necessary to ensure that the final equipment package will be consistent with the requirements of the operational concept and meet the expectations of the eventual user. The bulk of the information will come from the functional description identified in the planning stages, which dictates the equipment system types that will be necessary to accomplish those functions. These systems might include A/V, viewing and display, recording equipment, remote and direct control systems, editing, and storage. Communication systems, such as intercom or telephone, might be included. Basic equipment common to many laboratory applications is listed in Table 1. The Appendix contains an expanded equipment list.

Table 1 — Basic Equipment List

Video	Control unit
	Cassette recorders
	Monitors
	Cameras
Audio	Speakers
	Microphones
	Headphones
	Recording/playback equipment
Computer and Specialty	Computers and peripherals (disks and tape drivers)
	Terminals
	Printers
	Input devices, (joysticks, mice, track balls)
Miscellaneous	Spare parts and tools
	Extension cables and power strips
	Extra connectors
	Frames, racks, tables, and other laboratory furniture
	File cabinets, bookcases, and other kinds of storage for equipment literature, software and documentation, maintenance information, minor repair tools.

Lastly, specific equipment requirements need to be addressed. The coordinator can gather specific information by visiting other laboratories to observe and discuss the pros and cons of the equipment in use. If a hands-on approach is desired, product demonstrations or industry trade shows can be visited. After acquiring exposure to operational equipment, the coordinator will be able to give the equipment designer general guidelines on desirable equipment characteristics to incorporate into the final plan. Interequipment compatibility is important if cost is an issue. Flexibility of equipment and/or portability might also be major concerns. Some laboratory applications require complex equipment, and others require only basic systems to accomplish very specific or limited purposes.

Although the focus is on the equipment systems design, the coordinator should ensure that the contractor responsible for supplying the laboratory equipment considers other items. These include provisions for developing prototype systems, equipment tests, installation, wiring, post-installation adjustments, equipment substitutions (necessary to meet desired system specifications and/or functionality), follow-up visits, maintenance, and training or orientation for the new users. Guidelines are available to determine characteristics of the equipment systems. These are covered in the sections on equipment subsystems.

4.1 Audiovisual Systems

4.1.1 Cameras and Video Recording

Video cameras should be able to pan, tilt, zoom, and focus. Pan and tilt mechanisms should have smooth and quiet operation and a wide-angle range of motion. Desirable zoom mechanisms can automatically refocus when repositioned (sometimes known as perfect zoom), have variable zoom speed, and have silent or low-noise operation. Most video cameras specify a maximum cable length from camera to recording location. When selecting camera models, the size of the laboratory facility and the distance to the recording or control area must be considered.

If there is a need for equipment flexibility and for controlling costs, these can be achieved by limiting the number of cameras purchased and refraining from mounting them in fixed locations. Cameras can be mounted on movable tripods, if floor space permits, and if it is not too intrusive or disruptive to the experimental procedures being conducted. Alternatively, the camera system could be designed to allow cameras to be clamped or otherwise fixed to a new location on a ceiling-mounted grid framework or other support mechanism. This approach is similar in concept to that of track lighting, but would probably have to be custom made. If a movable camera system is necessary, adequate cable lengths must be provided.

The coordinator should compare the cost of a movable camera system with the need for flexibility and with the relative cost and adequacy of sophisticated panning and mounting mechanisms for fixed-location cameras. Then the need for such a system should be determined by studying the various types of experiments that are planned. For example, if multiple subject experiments are planned, there is a greater need for large camera angles and more complete room coverage for recording purposes. If a variety of experiments is planned that would require frequent reconfiguration of the camera system, the cost in lost time to reposition the cameras might outweigh the additional cost of providing an adequate fixed-camera system.

For normal and one-use recording needs, a standard VHS tape recorder/player system (or multiple systems for large facilities) will be adequate. Consider the high resolution benefits of three-quarter inch, U-matic tape player/recorder units if high resolution is needed or if tapes will be either reused or recopied repeatedly. Resolution is generally lost with consecutive tape duplication. Super VHS (S-VHS) systems provide higher resolution than standard VHS. Because VHS systems are still the most common, there is potential for incompatibility problems if U-matic, S-VHS or Beta systems are chosen and if the staff shares taped information with other facilities or organizations.

Videodisc recorders are suitable for special purpose operations, such as prototyping interactive video interfaces and single-frame recording used to generate animated video. Unfortunately, no erasable media are available for this technology, so the production expense is usually not justified unless extensive use will be made of the recording. With appropriate interfaces (as determined by a knowledgeable video systems designer), videodisc materials can be copied if needed for demonstration purposes.

Auxiliary components to consider in the A/V recording system might include a video control unit to monitor brightness, contrast, or other recording characteristics, or a video time stamper to label frames for later synchronization with other tapes. (See Sec. 4.1.2.) A special effects generator (SEG) included as part of the recording system allows input from multiple cameras to a single screen or allows superimposition of images on a single screen, among other special features. A coordinator interested in these or other special effects should request demonstrations of various SEG models before specifying a set of requirements. (See Sec. 4.2.)

4.1.2 Video Editing

In many facilities, the control room will be the most inexpensive place to edit video because it will probably include at least one video cassette recorder (VCR) (two are required for editing) and monitors for viewing recorded and edited material. Some VCRs include editing components; these will provide for most common editing needs. If specialized or sophisticated editing capabilities are required, a separate editing facility may be indicated. This separate facility need not be stationary; a portable (cart-mounted) editing facility may be the best solution if space is a problem or if flexibility is desired. A portable facility is also desirable because relocation of the equipment minimizes disruptions to other workers from editing noises. (See Sec. 4.5.)

Regardless of the system used, an upgraded, heavy-duty VCR capable of starting and stopping repeatedly without ruining the tape is preferred. The quality of the monitors included with the editing system depends on the nature of the editing tasks that are planned. The most desirable tape-editing systems are capable of time-code reading and frame counting, include a character inserter for labeling tapes, they also provide jitter-free editing.

4.1.3 Display Systems

4.1.3.1 Monitors — Professional quality monitors are recommended when selecting monitors that are 13 in. or less. Lesser quality can be used for larger monitors unless the particular application demands otherwise. A product demonstration will be helpful in selecting appropriate monitor quality levels. If color (as opposed to monochrome) monitors are chosen, those with color bar generators to facilitate adjustments are preferable. Monitors should be able to accept several inputs without recabling to allow channel switching, particularly when they are part of a multicamera system capable of multiple inputs.

4.1.3.2 Large-Screen Display Projection — If a large-screen display is planned, decide between rear and forward projection. Rear projection sometimes is desirable because of space limitations in the viewing area while there is ample projection space in an adjacent area. Rear projection allows freer movement within the viewing area because the light path is not interrupted by movement between the projector and the screen (as it would be with forward projection). Rear projection requires a projector that reverses images.

When selecting projection equipment, several performance factors must be considered. Resolution, brightness, number of dots per inch, number of lines per inch, and frequency influence the perceived quality of the projected image. Projection equipment selection varies depending on input signal acceptance requirements. Some kinds of projectors accept computer signals as input and some accept National Television Standards Committee (NTSC) video. NTSC is the accepted standard. Signal converters are available that allow some incompatible input signals to be used.

Consider, too, the size and shape of the projected image in relation to screen dimensions. Although screens can be custom ordered in virtually any size, the standard ratio of height to width is 1:1.3, and most projectors are designed to project an image that conforms to this standard.

Some projector manufacturers offer lens sets that allow adjustments to projected image size within the same height-to-width ratio. This is desirable when an improperly sized screen is part of the existing equipment inventory. Projected image shape is influenced by the mounting location of the projector. The best site is on the center of the projection area. If the mounting is too high or too low, the projected image takes on a trapezoidal shape, also referred to keystoning. Portable mounting, such as on a movable cart or tripod, is an alternative if the exact location of the projected image does not need to remain constant from one session to the next. Within limitations, use a portable projection arrangement to adjust the image size by moving the projector closer to or farther from the screen.

4.1.4 Audio Systems

A simple audio system will be sufficient for most HCI research needs. As a minimum, the audio system should include microphones and speakers in each experimental space and in the control room for live sound input and output. (See Sec. 4.3.) Several video monitors include audio amplifiers and speakers, and when these are selected for use in the control area, some duplication of equipment can be avoided. If simple audio recording or prerecorded audio presentation is planned, additional equipment should be added to the basic audio system equipment list. This includes at least two analog recorder/players with volume unit meters to monitor audio signal levels during recording, a good quality sound-level meter, headphones, and an amplifier. If extensive preparation of stimuli or demonstration tapes are required, an audio-mixing unit may also be needed. These can be cassette or reel-to-reel, depending on organizational needs. Reel-to-reel recorders provide higher quality recordings and playback and are preferable, if splicing is anticipated.

If voice or other sounds are to be recorded in undesired background noise, unidirectionally sensitive microphones help separate the desirable sound. Otherwise, omnidirectional microphones suffice. Microphone response characteristics also need to be considered. Microphones with a flat response over a wide frequency range are the most desirable and flexible. If the class of experiments planned includes motion on the part of the test participant, clip-on or wearable microphones help to maintain a more constant sound input level.

For sophisticated applications, a digital audio system may be appropriate. At press time, the laws governing the use of digital audio technology and the technology itself are rapidly changing. Consequently, we recommend expert consultation to any coordinator who might consider a digital audio system. Only general information is given here.

Digital audio offers advantages over analog systems. There is no tape deterioration over time (such as print-through distortions) with digital audio systems nor is there degradation of signal when tapes are copied (as there is with analog systems). The imprecision and tedium of cutting and splicing tape by hand are unnecessary with digital systems. Sound mixing, synthesis, and sampling are also simplified. A disadvantage of digital audio tape (DAT) is that it is subject to bit errors after 50 to 80 plays. As long as a backup copy of the original material is made before extensive playback, a pure copy can be maintained.

A minimal digital audio system might include two professional quality DAT recorders to perform digital-to-digital copying and editing without quality loss. The sampling rate should be considered because different devices may use different rates. In most cases, digital audio dubbing and limited editing equipment are built into the DAT recorders, but editing capabilities are less refined than with analog systems.

More accurate editing procedures can be accomplished by computer when analog-to-digital and digital-to-analog converters with appropriate interfaces are provided. Two-channel systems and graphic equalization capability are desirable for applications if emphasis or deemphasis of sound is planned. (This is often necessary when noisy environments are studied.) The disadvantage of computer-controlled signal manipulation and editing is the large amount of computer memory required to store audio signals.

4.2 Control Systems

The control panel or console consists primarily of a collection of mechanisms to control the A/V equipment. Standard equipment might include camera-positioning controls (such as pan, tilt, zoom, and focus) with video monitors to review camera adjustments. Video recorders and their associated peripherals (such as time code stampers and generators, character generators (for tape labeling), video mixing boards, and special-effects boards) are also often included. (See Sec. 4.1.1.) For complex A/V systems in large laboratories, the control console might be equipped with a signal matrix switch box or patch panel capable of routing input and output of A/V signals. In some applications, other controls for lighting and temperature are installed in the console so that all control equipment is housed in one centralized location.

Decentralized or remote equipment control may occasionally be desirable, particularly when staffing limitations do not allow full-time console operators. Lighting adjustment, camera positioning adjustments, and various display devices used during briefings or demonstrations can then be remotely controlled (see Sec. 4.4).

The size and shape of the control console will vary with the needs and scope of the control system. For a small operation that can be controlled by one or two operators, a crescent-shaped configuration will maximize equipment reach accessibility. If several people use the console at once, a straight line configuration provides more space between operators. A low-profile console obstructs the view less when used in conjunction with a one-way mirror and is easier to reach than a taller console. All control consoles should be equipped with a work surface for taking notes.

4.3 Communication Systems

An intercom system that allows communication between laboratory spaces and control areas is necessary. This system takes various forms and includes microphones, speakers, and headphones for communication between subjects and experimenters. Some telephone systems provide intercom capability and can sometimes be substituted for a separate intercom system.

An electronic signal communication system may be appropriate when demonstration or briefing space in the immediate area of the experimental spaces is limited or if there is a closed circuit television (CCTV) system already in place. If CCTV is available for input and output of A/V signals, any nearby conference room could be set up for use during presentations and demonstrations. If there is no internal television system, normal video input and output can be transported over cable to other site locations. This is appropriate if there is an existing presentation facility that could supplement display equipment associated with the new laboratory. Consider absolute distance from the source when selecting one or more satellite sites for remote viewing. The maximum allowable distance depends on the kind of signal, cable, camera quality, and other considerations that should be reviewed by a video system designer.

4.4 Computer Peripheral Devices and Specialty Media Presentation Equipment

The need for computer or specialties items varies with the goals of each facility or organization. Rather than attempt to evaluate machines for all possible uses, only general considerations are presented.

Existing computer equipment may be available for use in the new laboratory. A comprehensive computer equipment inventory should be made so computer needs can be addressed. As part of this inventory, the compatibility of available computer equipment with planned recording equipment must be assessed. The adequacy of existing equipment relative to the goals of the new facility must be determined. For example, those laboratories concerned with new HCI techniques will be more likely to include a variety of computer input devices on their equipment list (see Table 1).

If the emphasis is on simulating complex computer systems and there are several different kinds of computer equipment in use in one laboratory, there may be a strong need for interface devices or networks that will allow data to be transported from one computer system to another.

Many specialty devices will convert computer signals to standard video (e.g., digital–scan converters) and back again. Scan converters must be selected carefully because there is at present no universally compatible machine. It is also possible to take standard video (NTSC) and convert it to data that can be stored and edited through videodisc technology and then return it to video format. Some conversion technologies are relatively immature, so it is advisable to see a demonstration of presentation and other output equipment (such as printers) so the performance qualities can be assessed directly. Less sophisticated technology that will convert computer display images to a standard overhead projection format is available as a less costly alternative. It is also possible to purchase equipment to make viewgraphs from single frames of video. Almost all of these devices can be designed to be remotely controlled, and this should be considered in planning if an extensive presentation capability is desired.

4.5 Equipment and System Flexibility

Although intersystem flexibility is important when budgets are limited, it is also desirable when cost is not an issue because it allows efficient use of resources. The pros and cons of installing equipment in permanent locations should be carefully evaluated. In many cases, the best solution to an equipment–resource problem might allow for a nucleus of permanent equipment needed for daily operations along with a collection of special purpose equipment that can be made portable. Unless the appearance of the control room is extremely important, flexibility and portability are usually enhanced by mounting equipment in racks or on rolling carts fitted with wheel brakes. Likely candidates for portability are editing systems and viewing facilities (see Sec. 4.1.2).

We have discussed other opportunities for designing flexibility into the equipment system. These include the centralized control panel that would allow connections and reconnections to be made without expert knowledge. For example, video or audio output could be directed from one experiment room to another experiment room by the patch panel. Flexible switching capabilities may reduce the need for multiple pieces of equipment in large experimental facilities. Flexibility would be further enhanced by building in opportunities for remote viewing of laboratory activities such as presentations, demonstrations, and experiments as described in Sec. 4.3.

5.0 SUMMARY

This report outlines areas of concern applicable to the design and development of a research facility. It provides a tool with which the new facility design process can be organized. Table 2 might be useful during planning and when consulting contractors. The Contents can also be used as an expanded checklist.

Table 2 — Design Considerations Checklist

- System analysis
- Functional identification
- Operational requirements definition
- Functional area design
- Surface coverings
- Soundproofing
- Temperature control
- Lighting
- Electrical service and cabling
- One–way mirrors
- Safety and security
- Equipment

Because requirements vary among research groups, it is not practical to address every design requirement or consideration in detail. Rather, the reader is advised to enlist the assistance of expert consultants. Of these, the A/V system design professional is probably the most important to the success of the new facility. Because many possibilities and combinations of equipment exist and because technology is changing rapidly, expert consultation is critical.

In addition to obtaining specialized information throughout the design and development process, the wise laboratory coordinator will keep Woodson's general principles in mind [2]:

1. Plan first the the whole, then the parts.
2. Plan the ideal, then compromise with the possible.
3. Plan the layout around the system and its requirements.
4. Plan the final enclosure around the layout.

More specifically, the coordinator gathers as much information as possible about the specifics of the research mission, the number and type of personnel that will use the facility, and the necessary equipment items with their dimensions, functions, and interconnections. Then the designer defines and prioritizes functions and begins to lay out the important functions of people and equipment within the constraints of the available space. Secondary functions and their attendant equipment and personnel are considered next. Equipment, work locations, cost, and individual needs are adjusted to optimize the benefits and functionality of the final product [7].

6.0 ACKNOWLEDGMENTS

The author thanks Astrid Schmidt–Nielsen, whose critical reading and review of this report greatly enhanced its presentation, and to L. J. Chmura, for his encouragement.

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